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(71) Applicants
Sulzer Brothers Limited,
CH-8401 Winterthur,
Switzerland
(72) Inventor
Felix Streiff
(74) Agents
Kilburn & Strode,
30 John Street,
London WC1N 2DD

(54) Static mixer

(57) The invention provides a static mixing device comprising a tubular casing (1) and, disposed therein, at least one mixer element (2-5) in the form of crossed webs (6, 7) disposed at an angle with the tube axis, the webs being disposed in at least two groups, the webs of any one group of elements extending substantially parallel to one another and the webs of one group crossing the webs of the other group, in which the maximum web width (b) is from 0.1 to 0.167 times the tube diameter (d), the normal between-webs distance (m) in each group is from 0.2 to 0.4 times the tube diameter (d) and the length (l) of the mixer element is from 0.75 to 1.5 times the tube diameter (d).

Fig.1

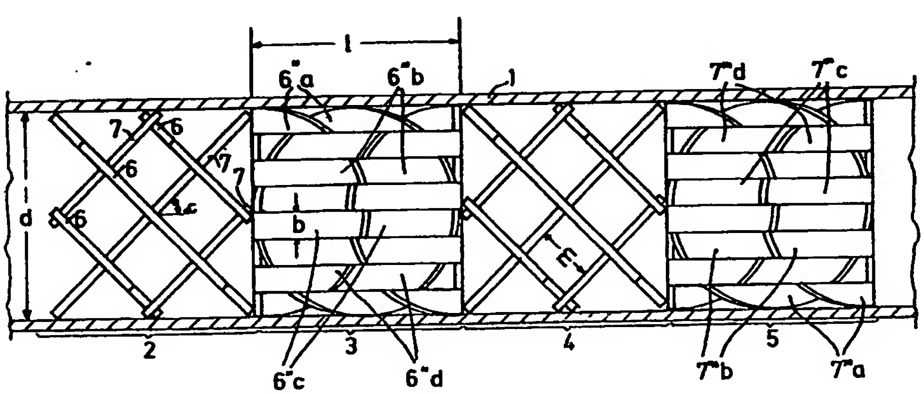

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Fig.1

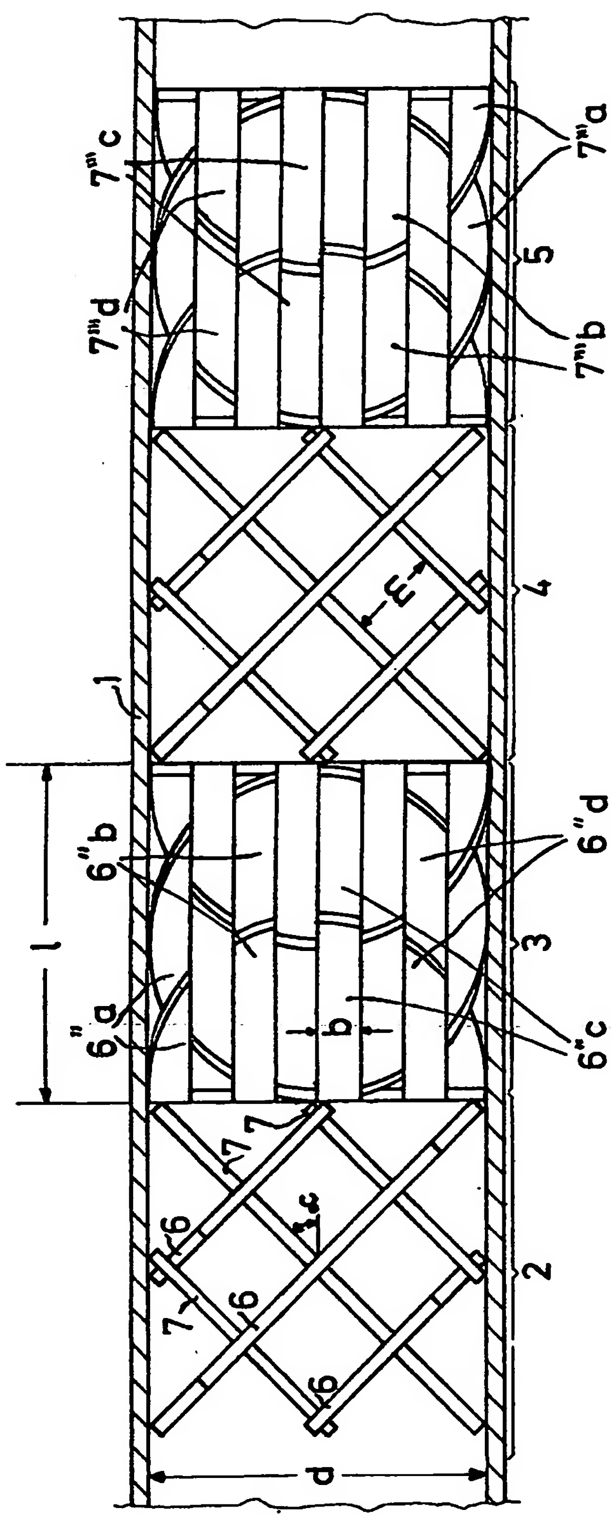

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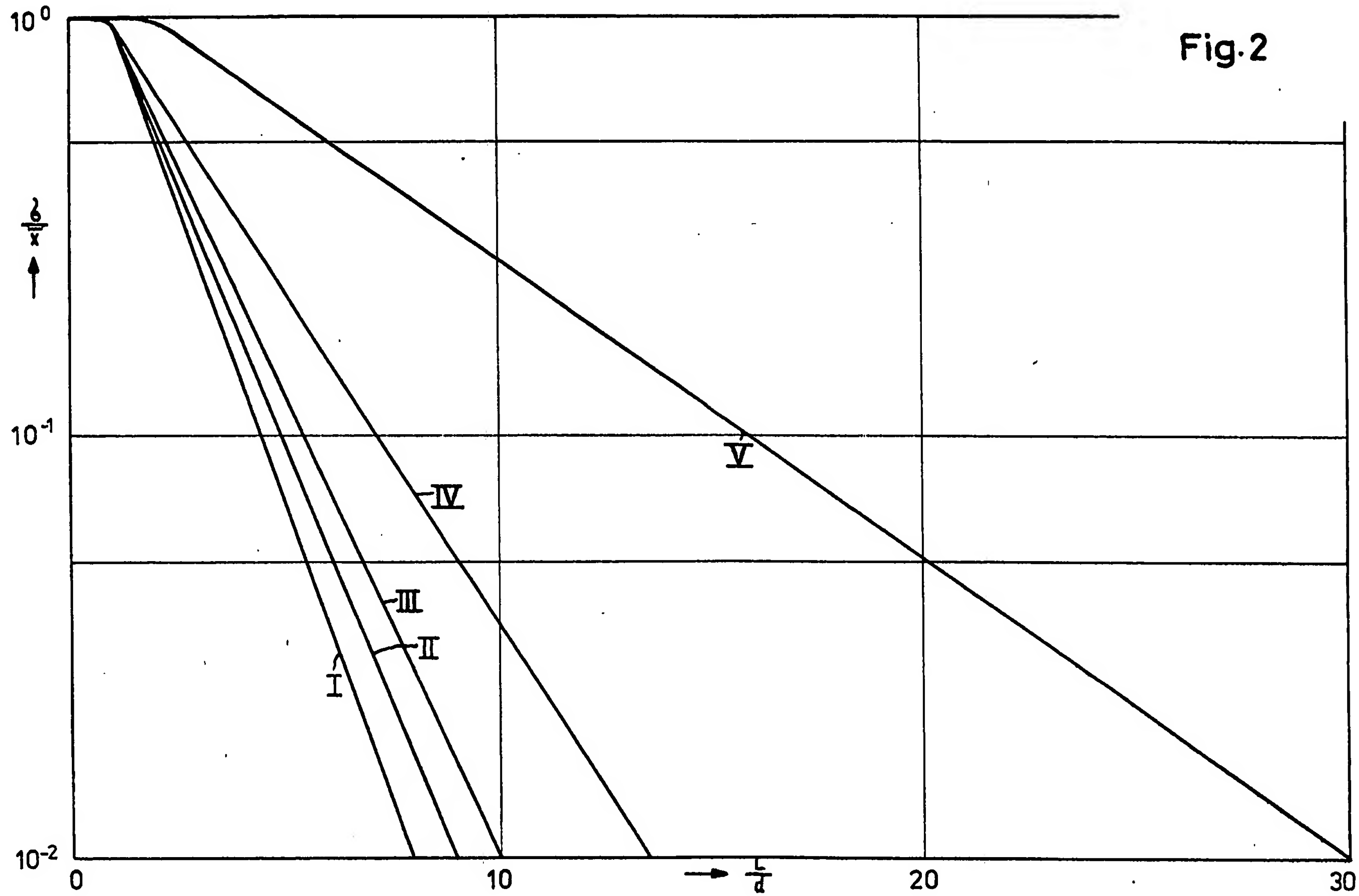
Fig. 2



SPECIFICATION

Static mixer

The invention relates to a static mixer.

Static mixers of the general type to which the invention relates, are known e.g. from German Auslegeschrifts 2,328,795 and 2,522,106.

Static mixers are required to be as short as possible for economic and technical reasons. Material costs and pressure drop in use are the economic considerations, while overall length should be short for technical reasons to ensure that the mixture is of compact construction and that the dwell time of the media in the mixer is short.

It has previously been assumed in practice that if a required level of homogeneity is required, e.g. in relation to concentration or temperature, mixer elements must have a large number of webs and the webs must be arranged in a narrow "pack" to give a small "mesh size". Mixer length then becomes relatively short. Unfortunately, it has been found in practice that this arrangement results in a considerable pressure drop, resulting in high pumping powers and therefore high energy costs; also, the mixer elements have to be very strong. Another difficulty is that mixer elements of this kind are different to clean and become clogged fairly readily because of deposits forming on the webs.

It therefore began to be thought that the pressure drop could be decreased by some "loosening-up" of the mixture element structure, i.e., by using fewer webs and by increasing mesh size. However, the layering laws for determining homogeneity show that such a construction would reduce the layers produced over a particular mixer length, so that the length would have to be increased, on the assumption that mixer length would have to be increased approximately in the same proportion as the pressure drop would be reduced. This construction was therefore not used in practice.

It is the object of the invention to provide a geometry for the known structure which provides the required mixing quality in a mixer of relatively reduced length and having a low pressure drop.

Accordingly the present invention provides a static mixing device comprising a tubular casing and, disposed therein, at least one mixer element in the form of crossed webs disposed at an angle with the tube axis, the webs being disposed in at least two groups, the webs of any one group of elements extending substantially parallel to one another, and the webs of one group crossing the webs of the other group, in which the maximum web width (b) is from 0.1 to 0.167 times the tube diameter (d), the normal between-webs distance (m) in each group is from 0.2 to 0.4 times the tube diameter (d) and the length (*l*) of the mixer element is from 0.75 to 1.5 times the tube diameter (d).

The surprising knowledge underlying the invention is that if the above dimension relationships are observed, the resulting mixer is only slightly longer than the conventional mixer and has an unexpectedly low pressure drop, as will be described hereinafter with reference to embodiments.

The invention is of use more particularly for mixing processes of Newtonian and non-Newtonian liquids.

The tubular casing can be a circular section tube or a square section tube. In the former case the contour of the webs is adapted to the circular cross-section of the cylindrical tube.

The geometry of the mixer elements is determined by the dimensional specifications for the relationship of web width *b* to tube diameter *d* and the relationship of the normal between-webs spacing *m* between adjacent group pairs to the tube diameter *d* and the relationship of mixer element length *l* to tube diameter *d*. For instance, the statement b/d = 0.167 means that six webs are distributed over the same tube-cross-section, whereas the statement b/d = 0.1 indicates that ten webs are distributed over the same tube cross-section.

The relationship between the normal spacing *m* and the tube diameter *d* denotes the web density in the tube – i.e., mesh size along the tube axis and therefore the total web surface area.

The relationship between mixer element length *l* and tube diameter *d* gives the length of a mixer element.

In order to promote a fuller understanding of the above and other aspects of the present invention, an embodiment will now be described, by way of example only, with reference to the accompanying drawings in which:–

Fig. 1 is a diagrammatic view in longitudinal section showing part of a mixer embodying the invention and

Fig. 2 is a diagram in which mixing quality, as indicated by the variation coefficient $\frac{\sigma}{X}$ is plotted against relative mixer length l/d.

Referring to Fig. 1, four mixer elements 2-5 are disposed one after another in a tube 1, each of the consecutive elements being rotated by 90° relatively to one another referred to the tube axis.

The elements of the embodiments each comprise two web groups 6, 7 and each group comprises webs *6'a, 6''a, 6'''a - 6'd, 6''d, 6'''d* and *7'a, 7''a, 7'''a - 7'd, 7''d, 7'''d*, the inclination angle α of the webs of group 6 being opposite to that of the webs of group 7. In the embodiment angle α is 45°. Each mixer element comprises three interleaved plate pairs *6'a - 6'd, 7'a - 7'd; 6''a - 6''d, 7''a - 7''d;* and *6'''a - 6'''d, 7'''a - 7'''d*, the webs of group 6 extending through the gaps between the webs of group 7 to cross the same while the webs of group 7 extend through the gaps between the webs of group 6 to cross the same.

In the embodiment each plate pair consists of eight webs, the webs of each plate being coplanar (see *6''a - 6''d* of element 3 and *7'''a - 7'''d* of element 5 in Fig. 1). However, the webs *6'a - 6'd, 7'a - 7'd* and so on, instead of being coplanar, can be offset from one another stairwise. As described in German Offenlegungsschrift 2,748,128, the webs of a single mixer element can be joined together at their contact places as a whole in a single working step by electric resistance welding.

The web widths have the references *b*, the tube diameter has the reference *d*, the normal distances

of the group pairs between the webs have the reference m, the angle of inclination of the group 6 and group 7 to the tube axis has the reference α and the length of the mixer elements has the reference l.

Five types of mixer elements will be compared hereinafter for measured pressure loss and relative mixer length with reference to the diagram shown in Fig. 2.

In the diagram the variation coefficient $\sigma/\bar{X}$ is plotted along the ordinate, and the relative mixer length l/d of the complete mixer comprising a number of mixer elements, is plotted along the abscissa. σ denotes the measured standard deviation from the calculated mean value $\bar{X}$ of a mixture produced in a static mixer.

The standard deviation σ from the calculated mean value $\bar{X}$ of the homogeneity of ingredients for mixing which a mixer provides can be found by means of electrical conductivity measurements (see Chem.-Ing. Techn. 51 (1979), Nr. 5, pp. 353-354).

The formal equation:

$$\Delta p = 32 \cdot Z \cdot \eta \cdot w \frac{L}{d} 2$$

is used for the pressure loss Δp found by measurements in static mixers, in the case of laminar flow. "z" is the pressure drop multiple and represents the relationship of the pressure conditions in a static mixer to the empty tube at the same viscosity η, flow velocity w, length L and tube diameter d.

The following table gives the geometric data for mixer types I-V.

Type	b/d	m/d	l/d	α
I	0,08	0,15	1,63	45°
II	0,1	0,2	0,75	45°
III	0,125	0,3	1	45°
IV	0,167	0,4	1,5	45°
V	0,25	0,5	1,6	45°

The characteristic curves $\sigma/\bar{X} = f(L/d)$ for types I - V are plotted in the diagram of Fig. 2 $\sigma/\bar{X} = 10^{-2}$ means that the standard deviation from the mean value is 1% and the mixture can be considered to be homogenous.

The table below gives measured values of relative mixer length for $\sigma/\bar{X} = 10^{-2}$ and the associated pressure drop multiples z for types I - V.

Type	L/d	z
I	8	90
II	9	50
III	10	35
IV	14	20
V	30	16

It can be gathered from the foregoing data that the relative mixer lengths II, III and IV are not much greater than for type I, but the pressure drop multiple of types II, III and IV can be reduced considerably below the pressure drop for type I.

It will also be apparent that pressure drop reduction is not in approximately the same relationship to increase in relative mixer length as has previously been assumed but is much stronger and more pronounced. Type I is of a construction similar to constructions disclosed in the publications cited in the introduction hereof.

A comparison of type V with types II - IV shows that the substantial reduction of the pressure drop multiple is linked with a substantial increase in relative mixer length; the increase of L/d and the decrease of z as compared with type 1 are in approximately the same relationship.

The interesting feature in a comparison of mixing devices with one another is the pressure drop/throughput for the same quality of mixing. The pressure drop and throughput are of course interconnected by way of the specific effect W which is a dimensionless characteristic (cf. e.g. E. Dolling: "Zur Darstellung von Mischvorgängen in hochviskosen Flussigkeiten", Dissertation, Techn. Hochschule Aachen/Germany/1971 and H. Brunemann and G. John: "Statische Mischer", Aufbereitungstechnik, 1972, 1, pp. 16-23).

$$W = \frac{\Delta pV}{\eta \dot{V}} = 32z\left(\frac{L}{d}\right)^2$$

in which ΔpV denotes the flow work, η denotes viscosity and $\dot{V}$ denotes volume flow.

For a given quality of mixing W is lowest for the technically optimal mixing device.

The following table gives the observed values of specific effect W for mixing devices for which mixer elements of types I - V are used.

Type	W
I	184 320
II	129 600
III	112 000
IV	125 440
V	460 800

As the table shows, a device having mixer elements III can be considered to be the technically optimal mixing device, although the difference from devices having mixer element types II and IV are so slight that the three types II, III and IV can be regarded as virtually equivalent. However, the specific effect W differs considerably for types I and V and can therefore be considered unsuitable for the purposes of the invention.

The surprising knowledge underlying the invention is based on the fact that the indirect proportionality previously assumed between pressure drop and mixer length is not continuous but that an optimisation range for the geometry of the known structures of static mixing devices exists where the mixers have a relatively short mixer length and an economically tolerable pressure drop.

CLAIMS

1. A static mixing device comprising a tubular casing and, disposed therein, at least one mixer element in the form of crossed webs disposed at an angle with the tube axis, the webs being disposed in at least two groups, the webs of any one group of elements extending substantially parallel to one another and the webs of one group crossing the webs of the other group, in which the maximum web width (b) is from 0.1 to 0.167 times the tube diameter (d), the normal between-webs distance (m) in each group is from 0.2 to 0.4 times the tube diameter (d) and the length (*l*) of the mixer element is from 0.75 to 1.5 times the tube diameter (d).

2. A device as claimed in Claim 1, in which the maximum web width (b) is 0.1 in which the tube diameter (d), the vertical between-webs distance (m) in each group is 0.2 of the web diameter and the length (*l*) of a mixer element is 0.75 of the tube diameter (d).

3. A device according to Claim 1, characterised in that the maximum web width (b) is 0.125 of the tube diameter (d), the vertical between-webs distance (m) in each group is 0.3 of the tube diameter (d) and the length (*l*) of a mixer element is equal to the tube diameter (d).

4. A device according to Claim 1, characterised in that the maximum width (b) is 0.167 times the tube diameter (d), the vertical between-webs distance (m) in each group is 0.4 times the tube diameter (d) and the length (*l*) of a mixer element is 1.5 times the tube diameter (d).

5. A device according to Claim 1, characterised in that at least two mixer elements are arranged consecutively in the tube and the adjacent elements are pivoted preferably at right-angles to one another referred to the tube axis.

6. A static mixer substantially as herein described with reference to the accompanying drawings.

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